THE RESEARCH AND DEVELOPMENT OF IGCC IN CHINA

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ABSTRACT

The 300~400MW IGCC demonstration project is started to build in China this year; the project may be completed in 2004. It will be the largest IGCC unit to use coal in the world. For the project, State Power Corporation of China and Ministry of Science and Technology of China have conducted many researches on the key technologies of IGCC, which involve in the integrated design and optimization of IGCC system, the gasification process, hot gas cleanup, the gas turbine and the heat recovery steam generator etc. These researches will provide good support for the Chinese first IGCC power plant.

1 THE DEVELOPMENT OF POWER INDUSTRY IN CHINA

The Current Situation

Since the founding of the People's Republic of China, the power industry has undergone rapid growth. In the times of central planned economy, this sector experienced serious power shortages for long periods. Thanks to the reformation and open to the outside world policy, now the installed power generation capacity in PRC is the second largest in the world, only next to the United States being in the first position.

According to the Electric Power Statistic Bulletin (Annual Estimation) issued by the Department of Strategic Study & Planning under the State Power Corporation on 30th December 1999. The nationwide power production, Investment and construction in 1999 had performed successfully and steadily entered into the new millennium. The development of power industry is closely associated with the development of national economy and the increase of energy demand.

By the end of 1999, the total installed power generation capacity reached 298.7GW; it was 7.75% over the previous year. In 1999, the national total electricity generation amounted to 1233.1 TWh; it was 6.52% over the previous year. Of which, hydropower amounted to 212.9 TWh, fossil-fired 1004.7 TWh and nuclear power 14.8 TWh, and they were 3.4%, 6.8% and 7.8% over the previous year respectively. The net coal consumption rate was 399 gce/kWh (7000 kcal/kg), or 5 gce/kWh lowered than the previous year. Table 1 and table 2 show the changes of total installed power generation capacity and total electricity generation in recent five years.

Table 1 Total installed capacity and composition

Year	Total Installed Capacity MW	Hydropower		Fossil-fired		Nuclear Power	
		MW	% of the total	MW	% of the total	MW	% of the total
1995	217224	52184	24.02	162940	75.01	2100	0.97
1996	236541.6	55577.9	23.50	178863.7	75.62	2100	0.89
1997	254238.2	59730.2	23.49	192408	75.68	2100	0.83
1998	277289	65065	23.46	209883.5	75.69	2100	0.76
1999	298767.9	72970.8	24.42	223434	74.79	2100	0.70

Table 2 Total electricity generation and composition

Year	Total Power Generation 10^9 kWh	Hydropower		Fossil-fired		Nuclear Power	
		10^9 kWh	% of the total	10^9 kWh	% of the total	10^9 kWh	% of the total
1995	1006.9	186.8	18.55	807.3	80.18	12.8	1.27
1996	1079.4	186.9	17.32	878.1	81.35	14.3	1.33
1997	1134.2	194.6	17.15	925.2	81.57	14.4	1.27
1998	1157.7	204.3	17.65	938.8	81.09	14.1	1.22
1999	1233.1	212.9	17.27	1004.7	81.48	14.8	1.20

Since 1998 in the whole economy the supply and demand of electric power has been relatively balanced under a low per capita power usage level. Serious power shortage has been basically relieved. In most regions, electric power supply capacity is even greater than demand, such as Northeast region, Central region and Southwest region etc. The average annual utilization hour of power generation equipment has been decreasing year after year, lowering to 4398 hours in 1999. The average annual utilization hour of fossil-fired units is 4811 hours. Table 3 shows the change of the average annual utilization hour and Net Coal Consumption Rate in recent five years.

Table 3 The average annual utilization hour and Net Coal Consumption Rate

Year	Utilization Hour			Net Coal Consumption Rate
	Hydropower	Fossil-fired	Total in Average	gec/kWh
1995	3857	5454	5121	412
1996	3570	5418	5033	410
1997	3387	5114	4765	408
1998	3319	4811	4501	404
1999	3198	4719	4398	399

Further development

Even though the total installed capacity and the total power generation of China now have reached the second place in the world, the per capita electric power utilization level is still low. Per capita installed capacity is only 0.222 kW, and per capita electricity utilization is only 927 kWh by the end of 1998, which is below the world average per capita power consumption in 1980. There is a gap of 30 years between the per capita power consumption level of China and that of the world. That means: China still has a long way to go.

According to the 9th Five-year Plan and predictions of the development of power industry for 2005,2010 and 2015, the total installed capacity will reach 290 GW by 2000 (this figure has exceeded already by the end of 1999), and the annual power generation will be 1,400 TWh. The total installed capacity shall reach 365 GW by 2005, 450 GW and 550 GW by 2010 and 2015 respectively. The annual power generation 1614 and 2520 TWh by 2005 and 2015 respectively.

China is a large coal production economy, with coal as the main fuel of power generation. This situation will remain unchanged in China for a long period. Among almost 300 GW of installed capacity, fossil-fired capacity takes 74.8%, the electricity generated from fossil-fired units takes more than 80% of the total. Coal-fired units account for more than 95% of the fossil-fired capacity. Most of them are sub critical units. There are only a few supercritical units in operation in China, totaling 5200 MW by June of 2000. The technical and economical performances of most coal-fired units are relatively backward. The national average net coal consumption rate is 399 gce/kWh in 1999, which is about 65 gce/kWh higher than that of industrial economies. Direct burning of coal and other fossil fuels causes acid rain over almost one third of China's territory. In 1998, total SO_2 and particulate

emissions were 20.9Mt and 14.5Mt. SO_2 emissions from industry were 15.9Mt, which accounted for 76.2% of the total SO_2 emissions in China and SO_2 emissions from power generation accounted for 35% of the total SO_2 emissions. Particulate emission from industry and power generation was 11.75Mt and 2.5Mt, which accounted for 80.9% and 17.2% of the total particulate emission respectively.

The current condition of low efficiency and high pollution of the fossil-fired power generation cannot meet the requirement of economic development in the 21st Century. The Chinese law of air pollution protection was newly revised and approved by the National People's Congress on 2000-4-29. It means a more strict regulation for power plant emission will come into execution. For the sustainable development of the electric power industry China has to continuously improve energy conversion efficiency and reduce emissions. The development strategy for power industry will be:

- Emphatically constructing power networks;
- Energetically developing hydropower;
- Optimizing development of thermal power;
- Appropriately developing nuclear power;
- Developing renewable energy in light of local conditions;
- Paying close attention to environmental protection;
- Stressing on development and conservation equally, so as to improve efficiency of energy utilization.

There is a prominent contradiction in the structure composition of installed thermal power generation capacity. There are about 30 GW of medium and low-pressure small condensing units with 50 MW and below, sharing about 15% of total fossil-fired capacity. The coal consumption rate of these units is very high, with low efficiency and high pollution, resulting in serious impact to the environmental protection and energy conservation. In the fossil-fired capacity composition, 300 MW and above units, 100 MW-210 MW units, and below 100 MW units, represent about one third respectively as shown in Table 4.

Table 4 Fossil-fired capacity composition in 1998

Unit size MW	Installed capacity MW	Share %	Parameters MPa/
Above 500	11680	5.5	16.6/538/538
300-360	56475	26.9	16.6/538/538
110-210	55530	26.5	12.2/535/535
100	14000	6.7	8.8/535
Below 100	72158*	34.4	

* Including gas turbine and diesel units in total about 10000 MW.

Facing the above conditions, China must simultaneously control total power quantity and speed up the pace of composition adjustment. Therefore, to adjust power structure and develop clean and high efficiency power generation technologies will be the basic choices for China over the next decades. To control total power quantity, China is limiting the construction of conventional coal-fired units 300 MW and below, but should not limit employing large units to replace small units retrofit projects, as well as projects utilizing foreign investment and comprehensive utilization projects. Supercritical pressure projects and clean coal power generation demonstration projects are certainly not limited.

Following measures will be taken to optimize the fossil-fired power generation structure:

- Shutdown small size units
- Develop thermal units with large size and high parameters
- Develop clean coal technologies
- Rehabilitation of old units
- Develop natural gas-fired combined cycle units
- Develop central heating and distributed co-generation units to improve energy utilization efficiency

In order to implement the strategy for sustainable electric power development, from 1994 the former Ministry of Electric Power of China has taken the clean coal power generation as one of the

scientific technical guiding projects crossing over the century. Now consequently the State Power Corporation has stepped into implementation stage of CCT projects, which includes supercritical units plus FGD, Integrated gasification combined cycle technology (IGCC), CFBC boilers and Pressurized fluidized bed combustion-combined cycle. It is unique to implement several different CCT demonstration projects for a developing economy over the same period.

2.I GCC Demonstration Project in China

The Preparation of IGCC Demonstration Project in China

Since 1993, some large size IGCC demonstration power plants have been built in US and Europe. The operation of these demonstration plants shows that IGCC systems can provide power at higher efficiency than PC plants, with significantly lower air emissions and a more benign solid by-product. Two issues concerned are: 1) While the reliability/availability of these units has improved since they were first brought on line, but some of them are not yet operating at commercially acceptable availability levels. 2) The cost of IGCC plant is still relatively higher than conventional PC plant with FGD. The developers and government sponsors of these demonstration projects understand this concern and are addressing it through continuing engineering efforts. Based on past experience in the development of new technologies, and assuming continued support by the various government and private parties involved, it is reasonable to expect that the problems will be solved within the next few years.

The high efficiency and low emissions of IGCC plants should be attractive to China in the long term. China began the technology feasibility studies on IGCC demonstration project in 1994. The studies were led by Thermal Power Research Institute (TPRI) of MEP (now SP). The main conclusions of this study include:

1) Based on the analysis of China's primary energy resources, the development of power industry and the situation of environment pollution, it was concluded that the current coal based power generation technology available in China could not meet the demand of the next century's development. Environmental impact will be a key factor in restricting the development of the power industry. So promoting the use of clean coal power generation technology with higher efficiency and lower emissions is especially important for China.

2) Three main coal-fired power generation technologies--pulverized coal-fired steam cycle; pressurized fluidized bed combined cycle; integrated coal gasification combined cycle--were analyzed and compared for their maturity, performance, economics, technical difficulties and other characteristics. It was concluded that all of these coal-fired power generation technologies could be applied suitably at different periods and in specific conditions, but IGCC technology is the most attractive option in the 21st century. There is great potential to further improve the efficiency and to reduce the capital costs. Therefore, this technology can meet the demands of a coordinated and sustained development of China's resources, economy and environment in the 21st century. Therefore developing IGCC is considered to be of great significance for China's power industry and priority should be placed on promoting development of IGCC technology and building an IGCC demonstration plant.

3) The IGCC plant to be built in China would be designed to demonstrate the new technology and to show its commercial value. Therefore, the system matching and selection of equipment and process configuration should favor advanced, proven and reliable technologies. A balance between plant investment and efficiency also needs to be considered in order to achieve the most optimal economic benefit.

4) The desired capacity of the IGCC demonstration unit was determined to be 200~400MW based on considerations such as conforming to the demand of the electric network, prospects for future development, technical and economic performance, etc.

5) In selecting gasification process, the entrained flow bed gasifiers were chosen after comparison was made on different gasification technologies. More than ten types of gasifiers in three technologies were analyzed. Among them Texaco, Destec, Prenflo, Shell, GSP and ABB-CE are entrained flow bed

gasifiers, HTW, U-gas and KWR are fluidized bed gasifiers, Lurgi and BGL are fixed bed gasifies. Because the entrained flow bed gasification process is the most proven technology for single unit with large capacity applications (greater than 2000 ton per day). It has become the technology of choice for large IGCC demonstration power plants in the world. The major candidates are the Texaco and Destec gasifiers, which are oxygen blown and slurry fed, and the Prenflo and Shell gasifiers, which are oxygen blown and dry pulverized coal fed.

6) A fully integrated air separation system can improve IGCC efficiency. However, this system may have some difficulties in plant operation. Therefore, it will be appropriate to select an independent or semi-independent air separation system for China's first IGCC demonstration plant.

7) Though research on hot gas cleanup technologies is being carried out intensively and great progress has been made in recent years, it is still in the stage of laboratory test and prototype demonstration. China's first IGCC demonstration plant is expected to adopt the mature low temperature cleanup technology for its syngas cleanup system. However, an interface for performing high temperature cleanup testing should be included in the IGCC plant design.

8) The extent of heat recovery from syngas has a direct effect on the overall efficiency, investment, and complexity of the IGCC plant. It is important to realize and consider heat recovery and efficiency trade-off, rather than just maximizing the efficiency performance alone.

The Information of the IGCC Project

In order to use advanced IGCC technology for power generation widely in the 21st century, China has made a decision to build a large-scale IGCC demonstration power plant. The State Power Corporation of China has planned to build a 300MW or 400MW IGCC demonstration unit at Yantai Power Plant in Shandong Province. The State development and Planning Commission had approved this project in 1999 and the bid for the project will be started this year.

Two 400-MW IGCC units could be installed in Yantai Power Plant after three existing units are removed. The plan is to first install one IGCC unit and leave the site for the rest. The planned capacity of a single IGCC unit is 300-400 MW with a net efficiency of more than 43%. It is designed to burn bituminous coal with high sulfur content (2.5-3%) from Yanzhou in Shandong. The gasifier will employ an oxygen-blown entrained-flow gasification process, which is the most proven technology for single-unit, large-capacity applications. It may be slurry-fed or dry pulverized-coal-fed. The mature low-temperature wet syngas cleanup process will be adopted. The sulfur will be recovered as elemental sulfur with a removal efficiency of 98%.

The international cooperation is very important for the IGCC demonstration project. Key components of the demonstration plant are imported, and trade & technology imported should be combined. Chinese IGCC development will be on a higher starting position. Under the prerequisite of guaranteeing Unit technology and product quality, parts of components should be manufactured in China to reduce cost and accelerate domestic Industry.

The project proposal had been approved in 1999 by government. At present, a guidance group of the project is formed, the bid items and the funds for the project has been prepared already Later this year or early next year, the bid will be started. During 2004~2005, the project will go to operation.

Demonstration Period and Content

- Demonstration duration is about 2~3 years
- Comprehensively Evaluate Demonstration Plant, and To Provide Valuable Experience for Future

IGCC Development & Application

- Unit Efficiency, Emission & Reliability to Reach Design Standards
- Further Improve & Optimize Operation and Control Strategies
- Conduct Tests for Varied Coal
- Availability to Reach 85%
- Conduct Life Test and Evaluation on Key Components

Market Assessment

Assuming the project at Yantai proceeds, it call reasonably be expected to be in commercial operation by 2005. Wider deployment of IGCC could, therefore, be forecast for the period beyond 2010. The market size will depend on the successfulness of the demonstration and the cost reduction.

In principle, IGCC plants can be designed to handle the range of coals in China. However, the high ash content of many Chinese coals would be economically unsuitable for the major commercially developed entrained-flow gasifiers such as Texaco, Destec, Shell, and Krupp-Uhde Prenflo designs. The coal/water-slurry-fed gasifiers rapidly degrade in performance as the ash content increases due to the reduced energy content of the slurry feed. Lower-ash-content coals are preferred for entrained-flow gasifiers. For higher-ash coals and low-rank coals such as lignite, fluidized-bed gasifiers would be the preferred choice; however these gasifiers are at a much earlier stage of development and are not ready for demonstration in China at this time.

In the meantime, however, there is a possible market for coal gasification technology in the non-power sector of China. A coal gasification concept worth pursuing in China is a co-production facility that would produce power, steam, and ammonia or other chemicals and fuel gases. Consideration of such a complex has been investigated for coalmines, petroleum refineries, and chemical industries.

3 RESEARCH ON IGCC KEY TECHNOLOGIES

China is currently conducting research preparatory for the building of an IGCC demonstration plant. This research will enhance understanding of advanced IGCC technology and proven commercial operating experience, as well as provide the technical basis and support for system selection, equipment import, and procurement. This research is sponsored by SSTC (now MST) and MEP (now SP) and addresses the following key aspects of the IGCC process:

Research on IGCC System Integration, Unit Operation and Automation Technology

1) Research on IGCC System & Its Characteristics
- Research on IGCC Thermal system characteristics and develop modular simulation software
- Optimization for IGCC subsystems and whole system integrity
- Optimization and evaluation on IGCC options with different gasification technologies

2) Research on IGCC Unit Operation Technology
- Analysis on operational characteristics of GTCC
- Calculation of partial load performance for IGCC
- Analysis on startup, shutdown & operational modes
- Demands of unit startup & operation on system design & automatic control strategy

3) Analysis on IGCC System Economy comparison for different CCT

4) Research on IGCC System Automatic control Technology
- Research on automation system of domestic GTCC
- Research on automation technology of foreign IGCC units
- Research on dynamic characteristics and simulation of IGCC system
- Research on overall system design for IGCC automatic-control mechanism

R&D on Key Technologies of Gasifier Engineering Utilization

- R&D on slurry feed entrained flow gasifier
  R&D on dry feed entrained flow gasifier
- R&D on fluidized bed gasifier
- Mathematical simulation for 4 gasification processes: Texaco, Destec, Shell, Prenflo
- To Compare and select gasification system and process

Hot Gas Cleanup

1) R&D on Process & Equipment for Hot Gas Dust Removal
- R&D on process & equipment for the metal filter
  R&D on process & equipment for the moving granular bed filter
- R&D on process & equipment for the ceramic filter
- Test for its performance and durability
- Research on two-phases flowing & separation mechanism for micro channel

2) R&D on Hot Gas Desulphurization and Regeneration

- R&D on high temperature desulphurization sorbent
- R&D on high temperature desulphurization and regeneration process
  Acceptance test for hot gas desulphurization process with one-litter capacity

3) Desulphurization sorbent, de-halide sorbent and others developed
4) To Compare & Select Processes & Components of Syngas Cleanup

Research on Gas Turbine Technology

1) Research on Gas Turbine Development Strategy in China
- Analyze experience & trend of GT development of the world
- Analyze GT status, energy distribution and market expectation
- Propose target and measure for GT development in China

2) GT Selection Principle & Technical Code for IGCC Unit
- Research on performance of GT capable of being used in IGCC
- IGCC demand on GT
- Development trend of GT used in IGCC

Research on Technology and Design Method for HRSG and Steam Turbine

1) Optimization Design for Steam System (HRSG & ST)
- Theoretical analysis on steam system of IGCC
- Mathematical model of steam system
- Optimization for steam system arrangement & parameters
- Analysis & evaluation on steam system of foreign IGCC plant

2) Optimization Design of Steam Turbine
- Optimization design of steam turbine with characteristics as: full-arc live-steam entering, multi-pressure steam addition, non-regeneration and/or partial regeneration
- Research on partial load performance with sliding pressure operation
- Research on high efficiency turbine blades
- Research on structure & system of quick startup steam turbine
- Steam turbine design case for 300/400MW IGCC

4 THE INTERNATIONAL COOPERATION OF IGCC

Continuous Cooperation between China and The United States

Close contact still remains between China and the Unit States on the IGCC project Representatives from the Department of Energy of US, as well as Texaco and GE companies provide up-to-date information about activities related to IGCC in the US. A joint pre-feasibility study for Chinese IGCC demonstration project based on Texaco gasification process was completed by NCEPDI, TPRI and Texaco in 1996. At present, it is planned to further this study in the following areas with funds from DOE and Ministry of Science and Technology (MOST) of China:
- To test coal used for the Chinese IGCC power plant
- Study on operation performance of IGCC power plant
- Workshop and training

A Cooperative Project on IGCC between China and the Netherlands

A memorandum of understanding on clean coal technology cooperation between MOST of China and the Ministry of Economic Affairs of the kingdom of the Netherlands was signed on 15 June 1995 in Beijing. An annex II was signed on 20 March 1997, between the MOST, SPC and NOVEM. The study agreement regarding a pre-feasibility study on the IGCC project of China was signed on 20 June 1997. TPRI and NCEPDI as the Chinese side cooperated with Shell as the Dutch side to have completed the pre-feasibility study in 1998.

The Pre-feasibility Study on IGCC Demonstration Project Conducted in Cooperation with ADB

A Memorandum of understanding for a proposed advisory technical assistance project on the clean coal (IGCC) study was signed between ADB and the People's Bank of China and SPC on March 11th. 1997. The objective of the study is to enable Chinese experts to assess the appropriateness of particular IGCC technology by providing technical information on maturity of technology, range of unit size available performance, capital cost and construction times. This will assist the SPC in choosing technology and size for China's first commercial scale IGCC demonstration plant that will be best suited to the practical situation pertaining in China. An international consultant group including EPRI of US, CRE of UK, TPRI and NCEPDI of China have completed the task of the project in 1999.

- Design, operation and equipment status of built IGCC plant of the worldwide comprehensively investigated
- Different characteristics of IGCC technologies compared & analyzed
- Technical case of China's IGCC plant proposed
- Design options of IGCC for Shell & Texaco gasification processes finished with ASPEN PLUS software

Partial Gasification Combined Cycle Power Generation Technology (ABGC)

The agreement regarding the ABGC technology between the China International Center for Economic & Technical Exchanges (CICETE) of Ministry of Foreign Trade and Economic Cooperation of China and ETSU of DTI of UK was signed on 17 February 2000. TPRI as the Chinese side cooperated with Mitsuibabcock as the UK side to being completing the project.

1. To develop & spread ABGC technology in cooperation with DTI of UK
2. To develop & spread ABGC technology in cooperation with China International Engineering Consulting Corp.

- System design & optimization for Air Blown gasification IGCC (ABGC)
- Partial gasification with air as oxidant
- Char combustion
- Hot gas cleanup
- Key technologies such as low-BTU syngas combustion

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